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A SKETCH OF THE HISTORY OF REFLEX ACTION.

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I.

BEGINNINGS AND DEVELOPMENT TO THE TIME OF CHARLES BELL.

The suggestions followed out in this chapter were obtained chiefly from notes made from the original sources in several of the libraries of Europe by Dr. G. Stanley Hall about the year 1880. At that time Dr. Hall was working upon reflex action in Ludwig's laboratory in Leipzig, and his object in going through the literature was that he might write a history of the subject in connection with his own work. In 1880 there was no history of reflex action later than Johann Wilhelm Arnold's[1] which appeared in 1842; and rapid progress since that time had rendered this inadequate for the needs of physiologists and doctors for whom it was written. But, as it often happens in science, when a need is felt, that several persons take up the work independently, Eckhard had been for a number of years collecting data for a history of this very subject. His admirable book[2] was published in 1881,

[1] Johann Wilhelm Arnold. Die Lehre von der Reflex-function für Physiologen und Aerzte. Heidelberg, 1842.

[2] C. Eckhard. Geschichte der Entwickelung der Lehre von den Reflexerscheinungen. Beiträge zur Anat. und Physiol. Vol. 9. Giessen, 1881.

PLATE II.

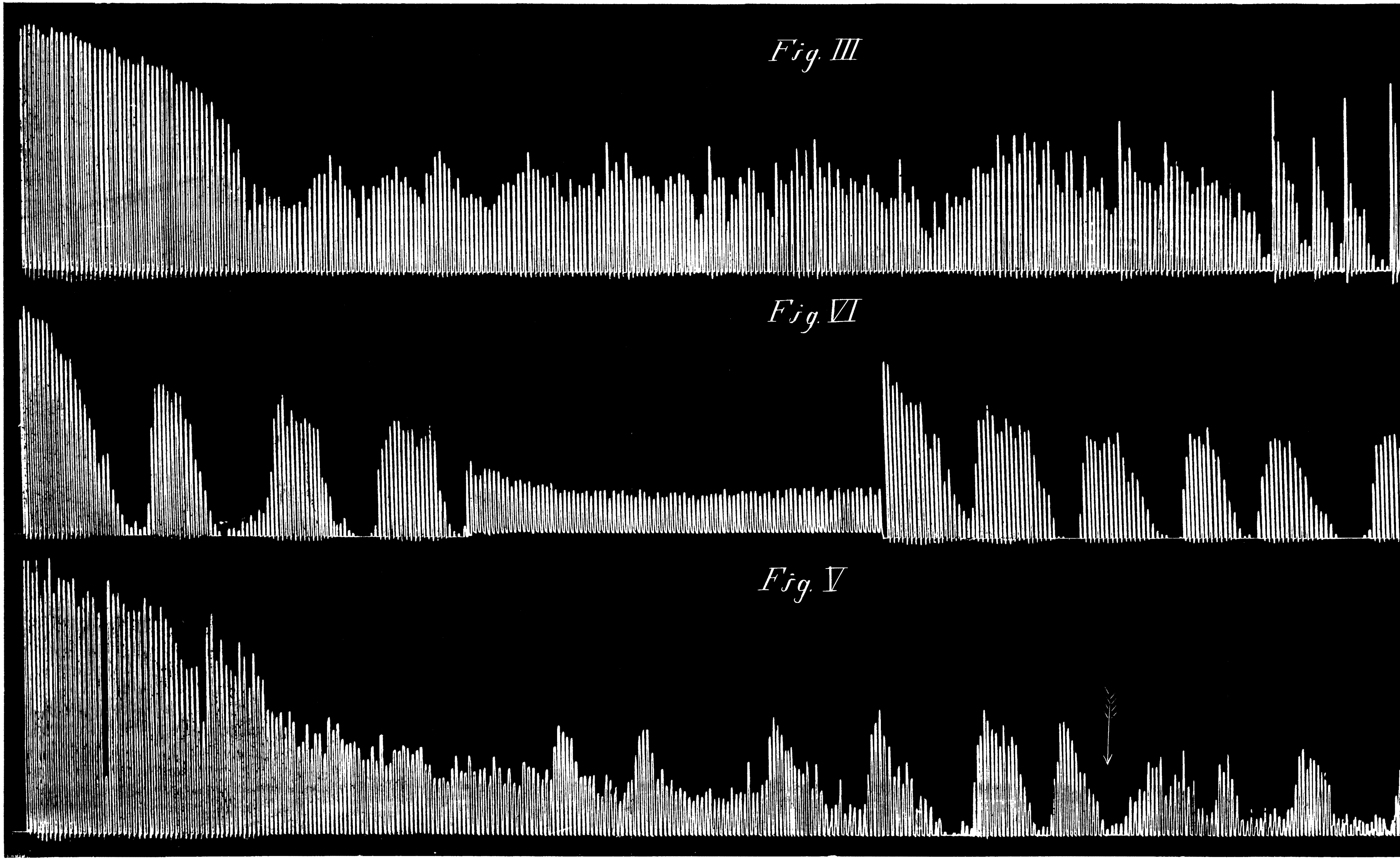


PLATE II.

Fig. III

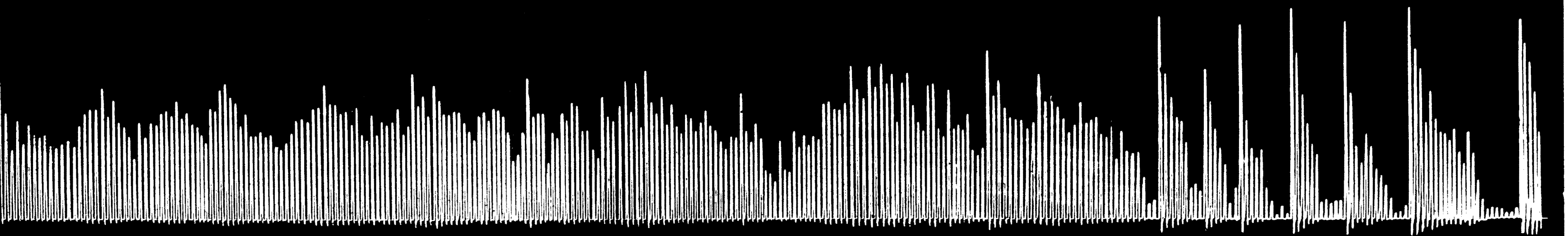


Fig. VI

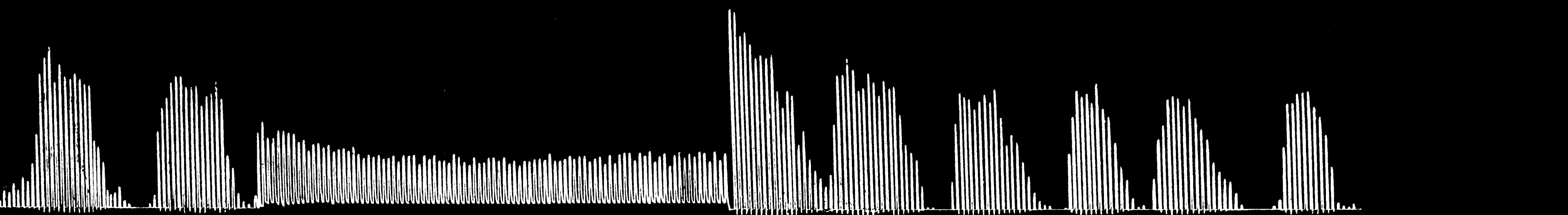
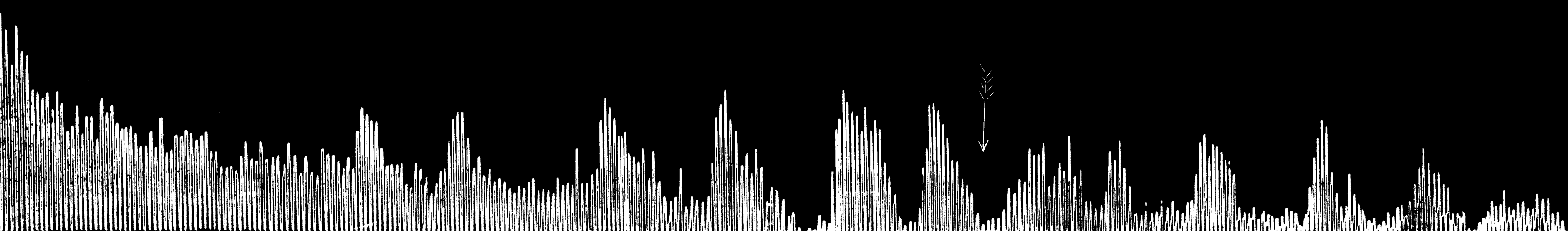


Fig. V



and seemed to meet the demand so fully that Dr. Hall laid his work aside for the time.

The two works were somewhat different in scope. With the one, interest centers about the facts of nerve physiology, with the other attention is directed to the psychological development which underlies the appreciation of facts and recognizes the value of experiment. For example, Eckhard says, "No doubt many true reflexes are included among the phenomena of the so called '*sympathies.*' To follow these out, however, has no interest for the experimental physiology of the nervous system."[1] This is in striking contrast to the way Dr. Hall has treated the subject in his introductory chapter,[2] where he brings out the underlying psychic relation between the quality of mind which produced the doctrine of sympathies of the older physiologists and that which gave rise to modern views of reflex action. It is there shown how the soul was at first thought to be able to produce sympathy between different parts of the body directly, without the mediation of any corporeal mechanism whatever. Later, when the arteries were supposed to contain the soul or "ether," these became indirectly the means of sympathy, and so on, until the arteries were proved to carry blood, and experimental evidence began to point to the nerves. Thus the reader is lead to see how the mind, from rejoicing in fanciful explanations of things, comes step by step to appreciate nature as it is, and to prefer plain reality to its own imaginings.

Endeavoring to retain this point of view we may take up the line of historical development at the time when the importance of the nervous system begins to be recognized.

With the revival of interest in anatomy under Vesalius (1514—1564), and its further progress under Dulaurens (1550—1609), by the close of the sixteenth century the nervous system had been fairly well distinguished from the other

[1] Beiträge, op. cit., p. 33.

[2] See this JOURNAL, Vol. III, No. 1. Introductory chapter to this subject.

tissues, and to it, in a theoretical way, had been ascribed certain functions of the soul. In some cases "sympathy" was said to be due to the connection of parts by nerves. For example, Dulaurens writing in 1595 ascribes the "sympathy" between the mammæ and the uterus in part to the "intercostal nerve" and in part to the azygous vein. It is not, however, until Descartes that we have the tangible beginning of what is to-day the science of reflex action.

The general neurological conceptions of Descartes may best be given in his own words:

"Although the soul is united with the whole body, its principal functions are, nevertheless, performed in the brain; it is here that it not only understands and imagines, but also feels; and this is effected by the intermediation of the nerves, which extend like delicate threads from the brain to all parts of the body, to which they are attached; so that we can hardly touch any part of the body without setting the extremity of some nerve in motion. This motion passes through the nerves to that part of the brain which is the common sensorium, as I have sufficiently explained in my Treatise on Dioptrics; and the movements which thus travel along the nerves to that part of the brain with which the soul is closely united, awaken by reason of their diverse characters different thoughts in the mind."[1]

Thus Descartes makes the brain pre-eminently the organ of the soul. But his views on this point were far ahead of his time, and he was obliged to contend against a strong current of opinions like those of Plato, who taught that the soul thought in the brain, felt passion in the heart, and desire in the liver. In these controversies Descartes' dissections stood him in good stead, as the following will show.

"The opinion of those who think that the soul receives its passions in the heart, is of no value; for it is founded only upon the fact that the passions cause a change to be felt in that organ; and it is easy to perceive that this change is felt, as if it were in the heart, only by the intermediation of a little nerve which descends from the brain to it; just as

[1] Œuvres de Descartes, publiées par Victor Cousin, Paris, 1824. Les principes de la philosophie. § 189, Vol. III, p. 500.

pain is felt, as if it were in the foot, by the intermediation of the nerves of the foot; and the stars are seen as if they were in the heavens, by the intermediation of their light and of the optic nerves. So that it is no more necessary for the soul to exert its functions immediately in the heart, to feel its passions there, than it is necessary that it should be in the heavens to see the stars there."[1]

We see from the above that Descartes had a clear idea of the sensory action of nerves. His conception of motor nerves is no less clear, although here the general ideas of his time cause a conspicuous bias. He says: "All the movements of the limbs, moreover, depend on the muscles; and finally we know that all these movements of the muscles, as well as all the senses, depend on the nerves, which are like little threads or tubes, all come from the brain, and like it, contain a very subtle air or wind, called animal spirits."

This leads us to Descartes' notion of the reflex process, which in essentials is as good as any we have to-day, viz, that a sensory impulse is carried to the brain and there may be, unconsciously or even in spite of the will, reflected, "*réflèchie*,"[2] to motor nerves and so cause a co-ordinated contraction of the muscles.

That "reflected" movements are effected by a corporeal machine, which may act in direct opposition to the volition of the soul, Descartes proves in the following suggestive language:

"And in addition to the different feelings excited in the soul by these different motions of the brain, the animal spirits, without the intervention of the soul, may take their course toward certain muscles, rather than toward others, and thus move the limbs, which I shall prove by an example. If some one moves his hand rapidly toward our eyes, as if to strike us, although we know that he is a friend, that he does it only in jest, and that he will be very careful to do us no harm, nevertheless it is difficult to refrain from closing them. And this shows that it is not by the agency of the soul that the eyes close, since this action is contrary to that volition,

[1] Les passions de l'ame, article XXXIII, op. cit., Vol. IV.
[2] Les passions de l'ame, article XXXVI, op. cit., Vol. IV.

which is the only, or at least the chief, function of the soul; but it is because the *mechanism of our body* is so constructed that the motion of the hand toward our eyes excites another movement in our brain, and this sends the animal spirits into those muscles which cause the eyelids to close."[1]

But Descartes goes even further, and outlines the great field of involuntary action in general, including actions which become reflex by habit and education. To quote again, he says:

"Yet I will say further that it appears to me a very remarkable circumstance that no movement can take place, either in the bodies of animals, or even in our own, if these bodies have not in themselves all the organs and instruments by means of which the very same movements could be accomplished in a machine. So that, even in us, the spirit, or the soul, does not directly move the limbs, but only determines the course of that very subtle liquid called animal spirits, which, flowing continually from the heart through the brain into the muscles, causes all the movements of our limbs, and often may effect many different motions, one as easily as the other. And the mind does not even always determine these movements, for among them there are many which do not depend upon the mind at all, such as the beating of the heart, the digestion of food, the nutrition, the respiration, of those who sleep; and, even in those who are awake, walking, singing, and other similar actions, when they are performed without the mind thinking about them. And, when one who falls from a height throws his hands forward to save his head, it is through no process of reasoning that he performs this action; it does not depend upon his mind, but takes place merely because his senses being affected by the present danger, some change arises in his brain which determines the animal spirits to pass thence into the nerves, in such a manner as is required to produce this motion, in the same way as in a machine, and without the mind being able to hinder it."[2]

It is suggestive to see how instantly the mind, set free from

[1] Les passions de l'ame, article XIII, op. cit., Vol. IV.
[2] Op. cit., Objections et Réponses, Vol. II, p. 52.

the perplexing trrationalfty ofsan immaterial principle acting lawlessly in the body, seeks the lawful mechanical explanation of the phenomena of life. It is suggestive, too, that mechanism is so readily found by him who seeks in the right spirit. So from the thought of Descartes sprang, full formed, the principle of mechanical physiology, and with it that of reflex action.

It would hardly be fair to ask of Descartes now-a-days proofs for all his statements. Some of his proofs are as good as any we have to-day; others are as fanciful as his reason for placing the soul in connection with the pineal gland. What to us are shadows were solidest realities to the men of his time. The soul as a separate entity was as real to Descartes as his own body; and "animal spirits," as a "subtle liquid," was as familiar to all the philosophers of that time as ordinary blood is to us to-day.

It is a great descent from the clear views of Descartes to the obscure ideas of his contemporaries and even of those who follow him. But there are compensations; for we shall exchange in a measure the highways of philosophy for the by-paths of experiment.

Reflex phenomena begin to strike the attention of a number of observers independently. Swammerdam (1637—1680), notices the reflex movements of sleeping animals and men, when the skin is gently stimulated. Francesco Redi (1626—1694), in Pisa, in connection with his work on the venom of serpents, has his attention called to the movements of animals after decapitation. Boyle (1626—1669), in England, describes the same phenomena in decapitated serpents as follows: "The body of vipers may be sometimes, two or three days after the skin, heart, and all the entrails are separated from it, seen to move in a twining or wriggling manner, nay, may appear to be manifestly sensible of punctures, being put into a fresh and vivid motion, when it lay still before, upon the being pricked especially on the spine or marrow, with a pin or needle."[1] It is difficult to conceive ho Descartes could have refrained from putting his notions

[1]C. Eckhard, op. cit., p. 38.

of reflex action to the test of experiment by vivisection. Had he done so, however, he must have discovered that the spinal cord, as well as the brain, could function as a "reflection" center. But here Descartes fell short, and now it appears that animals without the brain, the drive wheel of Descartes' whole machine, retain the power of responding to stimuli by reflected contractions. This brings the question to the point, viz: does this power have its seat in the body generally or in the spinal cord? As decapitation had demonstrated that it did not reside wholly in the brain, so one crucial experiment, the removal of the spinal marrow, would have demonstrated that it *is not present* in the body in general. But instead of making this experiment, the learned doctors turned to speculation and controversy as was their wont before Bacon tried to teach them a better way of using their time. A century elapses before the simple experiment is made, and meanwhile, the fight goes on about the soul, its location in the body, its connection and relation to it, its divisibility, etc., etc.; and added to this was discussed the question, whether "*sympathy*" depended on union of nerves in the spinal cord, their union at the periphery, or on blood vessels and continuity of tissues.

To Thomas Willis (1622—1675) is generally ascribed the origination of the notion of peripheral nerve anastomoses.[1] If this is true, Willis required his good work in brain anatomy to atone for such a mistake. And still, Willis wrote his "Cerebri Anatome" in 1664. In 1628 Harvey published his work on the circulation of the blood. And just before Willis wrote (1661), Malpighi supplied the one remaining link in the evidence for Harvey's doctrine by discovering the capillaries. It was a time when everything possible in the body must circulate, and in order for the "subtle liquid" within the nerves to do this, peripheral connections must exist between efferent and afferent nerves as between arteries and veins.

[1] "Dr. Willis, who has given a more accurate description of the brain and nerves than any anatomist before him, endeavored, first, to explain the various instances of sympathy between the parts of the body, from the connection or communication of their nerves. This doctrine was afterwards further illustrated by Vieussens, and has been embraced by most of the later writers." Works of Robert Whytt, Edinburg, 1768, oot-note, p. 50

The pressure of theory was, in short, strong enough to make some men see what did not exist. And Willis, "a lucky dissector, but a hair-splitting theorist,"[1] seems to have been the sort of man to see in this way. As Ridley, writing in 1695, quaintly put it: "I am apt to think that that learned person [Willis] too soon fell in love with his first thoughts, the ordinary reason of either one's seeing false, or not far enough."[2]

Willis was to some extent a student of Descartes, to whose influence he probably owed his bent toward the study of the nervous system. For things which Descartes treated in general terms, Willis naturally sought to discover special mechanisms. Thus, he says, if the brain secretes the "spiritus animalis," it, in turn, must obtain the nourishment which enables it to do so from the blood. This led Willis to study the blood supply of the brain, and the memory of his work in this direction is fitly perpetuated in the arterial ring which bears his name, the circle of Willis. He further correctly describes how the blood vessels of the brain distribute themselves and finally penetrate the surface in order to convey to the small nerves therein a delicate liquor which serves for the production of the spiritus animalis. The flow of the spiritus is determined by the convolutions, and each of these consists of two distinct substances, the gray and the white. Willis further considers that the actual secretion of the spiritus animalis must chiefly take place in the gray matter for the very good reason that the white resembles the matter of the nerves and spinal cord and to it should be ascribed the same function, viz.: the storage and distribution of the spiritus animalis.[3] In the matter of reflex action, Willis follows Descartes in the use of the term, "reflexa" and in general thought, likening the reflex process to that of reflected sound in echo, but differs from him in making the periphery as well as the brain the seat of the reflex process.

After Willis, Astruc of Montpelier (1684—1766), carried

Sprengel. Geschichte der Arzneykunde, 1827, Vol. IV, p. 201.
[2] Ridley. Anatomy of the Brain, London, 1695, p. 160.
[3] Willis, Cerebri Anatome, Amst., 1664, pp. 46, 49, 50.

out the suggestions of Descartes in a most rigidly mechanical way. He grouped sympathies, however, in the old style into several classes according as he supposed them to be explained by anastomoses of veins, continuity of tissue, anatomical or physiological resemblance, or by the nervous system. These latter, including respiration, deglutition, defecation, parturition, hysteria, teething-convulsions, and winking, are true reflexes. The brain he thought to be formed of tubes closely pressed together and often interrupted by columns of tendinous fibers. Against these columns the nerve tubes opened and upon them the spiritus animalis beat, the flux and reflux causing sensation and motion. As with light, angles of incidence and reflection are equal, so that a sensation produced by a concussion of animal spirits against the fibrous columns is reflected and causes motion in those nerve tubes which happen to be placed exactly in the line of reflection. The force with which the animal spirits impinge, however, may be so great as to cause motion in the nerve tubes on the other side of a column, thus producing an irradiation of reflected motion which might change the angle of reflection one hundred and eighty degrees.[1]

This work of Astruc was published in 1743. In 1751 appeared the celebrated essay of Robert Whytt (1714—1766), upon the "Vital and other Involuntary Motions of Animals." Section 1, of this essay opens as follows:

"A certain power or influence lodged in the brain, spinal marrow, and nerves, is either the immediate cause of the contraction of the muscles of animals, or, at least, necessary to it.

"The truth of this appears from the convulsive motions and palsies affecting the muscles when the *medulla cerebri*, *medulla oblongata* and *spinalis*, are pricked, or any other way irritated or compressed; as well as from observing that animals lose the power of moving their muscles, as soon as the nerve or nerves belonging to them are strongly compressed, cut through, or otherwise destroyed."[2] "The tying or cut-

[1] Cayrade. Recherches sur Mouvements Réflexes. Paris, 1864, p. 13. Cayrade makes Astruc the first to use the term reflex; but he has certainly overlooked the claims of Descartes and Willis in this matter.

[2] The Works of Robert Whytt, Edinburg, 1768, p. 3.

ting of blood vessels," he further adds, "has no such sudden effect upon the muscles," citing in proof the case of a dog which continued to use its leg, after the "crural" artery had been tied, "until the member was almost quite dead."

At the very outset, too, Whytt breaks away from the old overgrown ideas clustering about the term "animal spirits," declaring his preference for the expression, "power or influence of the nerves," and he adds: "If, in compliance with custom, I shall at any time give it the name of *animal* or *vital spirits*, I desire it may be understood to be without any view of ascertaining its particular nature or manner of acting." His division of animal movements is also good; but it is in a somewhat later work[1] that Whytt elaborates his views of reflex or sympathetic action. Here he enumerates many instances of normal and morbid sympathy, by which a stimulus applied at one part causes motion in a distant part. He especially calls attention to the fact that this may occur where no neural connection exists between the parts except through the brain and spinal cord. These, he justly urges, cannot be explained on the theory of anastomoses; and although he nowhere denies the possibility of such connections of nerves at the periphery, he brings forward a number of facts to disprove their effectiveness.[2]

"There can be no sympathy," he argues, "between the nerves derived from the same trunk by means of the membranes that surround them;" "because they have only an obtuse kind of feeling," "and no moving power," "and such connections would cause confusion in our sensations and motions." Moreover in cases of general convul-

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[1] Observations on the Nature, Cause and Cure of those Disorders which are commonly called Nervous, Hypochondriac or Hysteric. Edinburg, 1764. Works of Robert Whytt, Edinburg, 1768, p. 487.

[2] The best statement of Whytt's position in this matter is given in the following foot-note, which shows also the scientific spirit of the man.

"If it should be objected, that it is as difficult to account for a sympathy between the nerves at their origin in the brain, as in their course to the several parts, to which they happen to be connected; I answer, that the purpose of these observations is not to explain how the different parts of the body can be endowed, by means of the nerves, either with a sentient or a sympathetic power; but, to endeavor to trace the sympathy of the nerves to its true source, which I take to be the brain and spinal marrow." Whytt, op. cit., p. 512, foot-note.

sions caused by slight local irritation these connections, if admitted, must be assumed to be very extended; and still between parts close together and connected by nerves, sympathy is lacking, while it exists between distant parts. But all these arguments amount to but very little against the theory of anastomoses as compared with the fundamental and crucial experiment which Whytt brought forward. He says in describing this experiment: "When any of the muscles of the leg of a frog are pricked, most of the muscles of the legs and thighs contract, even after cutting off the head, if the spinal marrow be left entire; but when that is destroyed, although the fibres of the stimulated muscles respond with a weak tremulous motion, the neighboring muscles remain wholly at rest. There is no sympathy between the different muscles or other parts of the body as was observed while the spinal marrow was entire; from whence it seems to follow that the nerves distributed to the several parts of the body have no communication, but at their termination in the brain or spinal marrow, and that to this, perhaps, alone is owing the consent or sympathy between them."[1] The name of Dr. Hales is often coupled with this experiment, and justly so from Whytt's own account, which is as follows: "The late reverend and learned Dr. Hales informed me that having many years since tied a ligature about the neck of a frog to prevent any effusion of blood, he cut off its head, and thirty hours after observed the blood circulating freely in the web of the foot; the frog also at this time moved its body when stimulated, but that on thrusting a needle down the spinal marrow, the animal was strongly convulsed and immediately after became motionless."[2] These experiments prove that even if anastomoses existed they could not in any case mediate consent or sympathy between different parts.

Besides this, Whytt made several minor contributions to the subject. He has precedence in the discovery that, in the frog, a segment of the cord may serve to produce "consent" between the muscles to which it supplies nerves. It is Whytt, too, who seems first to have noticed that immediately

[1] Works of Robert Whytt, Edinburg, 1768, p. 520.
[2] Whytt, op. cit., p. 290.

after decapitation no sympathetic contractions could be called forth, thus anticipating the notion of inhibitory action. Finally Whytt brought the action of glands, the secretion of tears and saliva, into the category of reflex actions.

And yet with all this Whytt failed in his grasp of an important side of the subject. He repudiated the efficiency of mechanism utterly. With Whytt it is a sentient or vital principle that is behind all phenomena of life. To quote his own words: "The more probable opinion seems to be that the soul is equally present in the extremities of the nerves through the whole body as in the brain. In these it is only capable of feeling, or simple sensation; but in this it exercises its power of reflex consciousness and reason."[1] He believed in consciousness of different degrees, and that no motion can take place in the body unattended by some degree of consciousness. "The soul is diffused through a great part of the brain and spinal marrow, and might be present at one and the same time in all parts of the body where nerves are found." Yet he distinctly rejects the doctrine of Stahl that the soul directs all the bodily functions with a full degree of rational consciousness.

"We must either allow," concludes Whytt, "that both the head and body of a frog continue to be animated for some time after they are separated from each other, or else affirm that the life, feeling, and active power of animals are merely properties of that kind of matter of which they are made. The former opinion is attended with some difficulties which arise chiefly from our own ignorance of the nature of immaterial beings." "The latter view seems to be inconsistent with all the known properties of matter. If the latter, therefore, be admitted, we not only ascribe qualities to matter which it does not possess, but presume to limit, by our own narrow capacities, the power of incorporeal natures and their manner of acting upon bodies co-existing with them."[2]

These views brought Whytt into direct collision with Haller (1708—1777). For Haller had become imbued with the idea that there was a power inherent in living muscle,

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[1] Whytt, op. cit., p. 288.
[2] Whytt, op. cit. p. 289.

"*irritability*," "*vis in sita*," which was independent of the "*sensibility*" of nerves; and, although he takes for granted the existence of animal spirits and even discusses at length what manner of fluid it is, he seems to have been first to discern inherent in living nerves a something inexplicable on then existing theories, and to this something Haller first applied the term, the equivalent of Whytt's "power of nerves," "*vis nervosa*." But Haller's commendable zeal for the independence of irritability from sensibility led him too far. In order to prove this, he argues at great length that the pleura, peritoneum, bones, periosteum, ligaments, cornea, and some other tissues, are entirely without nerves and therefore insensible. And since these are destitute of nerves, the theory of Whytt must be amended by allowing that certain sympathetic actions, like the secretion of the lachrymal gland upon irritation of the cornea, must be due to simple continuity of tissues. Whytt had no method then at his disposal to demonstrate the nerves of the cornea, and even he does not seem to have thought of destroying the brain to see if the sympathy persisted. He attacked the matter from the other side, however, and gives Haller an able and suggestive answer.

"Having been lately present," he says, "at the extraction of the crystalline lense in Mr. Sharp's method, I inquired particularly of the patient whether he felt any pain when the *cornea* was first pierced with the knife? He told me he thought the pain was much the same with what he used to feel when the skin of his arm was cut in bleeding. It ought, however, to be remarked, that though the skin and *cornea* have both considerable degree of sensibility; yet, when they are cut quickly with a very sharp instrument, there is less pain felt than one would imagine."[1] "The tunica cornea is so far from being insensible, as M. De Haller believes, that any one may be soon convinced of the contrary by an experiment upon his own eye; for when the cornea is touched with the finger a sensible pain is felt; and it is well known that powder of tobacco, or any acid liquor applied to the *cornea*, excites a very acute sensation. Tho' the sclerotic coat of the eye is

[1] Whytt, op. cit., p. 263.

far from being void of feeling, yet I have found it less sensible than the cornea, by touching both not only with my finger, but with a bit of soft silk or linen."[1] Since Haller's method of demonstrating sensibility was simply to stimulate the part and notice whether the animal gave signs of pain, and since he expressly includes the conjunctiva with the cornea, these arguments of Whytt are perfectly conclusive. In a similar manner Whytt deals with all the "insensible" tissues of Haller, and is justly led to conclude "If sensibility, then, be a sure mark of the existence of nerves in any part of the body, there is none without them, altho' anatomists will never be able to demonstrate them in every part."[2]

About this time begins a department of our subject which will demand attention in a subsequent chapter, viz.: the rate of the nerve impulse. Shortly before the time of which we are speaking, in 1676, Roemer calculated for the first time the velocity of light. About this time, too, Newton, Hooke and Huygens, between them had developed the idea of the hypothetical ether, which was either projected, or transmitted waves of vibration with the velocity of light. Newton himself was among the first to carry this conception over into the theories of nerve action. In the *Principia*, he advances the opinion that all sensations and movements are excited by the vibrations of a "very subtle spirit" propagated through the solid "capillamenta" of the nerves from the organs of sense to the brain and from the brain to the muscles.[3] In 1649, David Hartley developed this opinion of Newton's into the celebrated vibration theory, calling into action the ether as the subtle fluid of the nerves. This theory suggested a rate of nerve impulse equaling the velocity of light. Another writer of the time calculated the rate of a nerve impulse from the velocity of the blood in the aorta, basing his computation on the theory that the nerve fluid traveled as many times faster than the blood, as the smallest nerve fibril he could find was smaller than the aorta. This gave the

[1] Whytt, op. cit. p. 262.
[2] Whytt, op. cit. p. 268.
[3] McKenderick. A Lecture on Physiological Discovery, Brit. Med. Jour., 1883, p. 995.

unthinkable velocity of over ten million miles per second.[1] By a simple and suggestive experiment, Haller checked the tendency toward such fantastic ideas and instilled into the subject a spirit of moderation, which may very possibly have hinted to Helmholz his method of actually measuring the rate of a nerve impulse. Haller's method was, briefly, to read a number of lines from the Æneid, take the time, count the letters read, and measure the length of nerve traversed by the impulse in speaking. The notions of centrifugal and centripetal were not so clearly defined then as now, and Haller made his computation on the assumption that the nerve current passed to and from the brain at each effort. But the rate which he obtained, although accidental, was not far from correct, viz.: 150 feet per second as compared with 90 feet, the result of Helmholz' measurement on the nerves of the frog.

But Haller missed the exact point, the unconscious element of reflex action; for he maintained that the processes in the movements of an animal with and without brain were in essentials the same; whereas herein lies the chief distinction.

Closely following Whytt began the writings of Johann August Unzer, (1727–1799), his "Grundriss," appearing in 1768, and "Physiologie" in 1771. By calling attention to the fact that artificial stimulation, whenever applied to a nerve trunk, produces the same effect as normal irritation, he could point out more clearly than had been done, the path of a sensory impulse from the periphery to the brain. Here, according to Unzer, it is transformed into a "material idea," which gives rise to an image in the soul; and from the brain it may pass as a motor impulse to the appropriate nerves and thence to the muscles to give rise to what Unzer calls "*motion with consciousness.*" From this, he distinguishes *unconscious* movements in which the sensory stimulus is, "bent back," "turned about," reflected" to the proper motor nerve without going up to the brain.[2] Unzer failed to appreciate the significance of Whytt's crucial experiment and taught that the reflection

[1] Hermann's Handbuch d. Physiol., Vol. II, p. 14.
[2] Arnold, Johann Wm. op. cit., p. 29 ff.

took place in the ganglia where the spinal roots diverge to enter the cord.

With Unzer came not so much anything new as a general clearing up of the subject preparatory to modern views of the relation between the mind and nervous system. The one to work more especially in the field of reflex action at this time was a contemporary and follower of Unzer, George Prochaska (1749—1820).

Writers, fifty years ago, could not say enough in praise of Prochaska's work. Longet ascribes to him the merit of making reflexes a distinct class of movements.

Prochaska's first important work was published in 1784, and a few words from this will best serve to indicate his earlier views of nervous action.

"At length," he says, "we abandon the Cartesian method of philosophizing in this part of animal physics, and embrace the Newtonian, being persuaded that the slow, nay, the most uncertain road to truth is that by hypothesis and conjecture, but by far the more certain, more excellent, and the shorter way is that, *quæ a posteriori ad causam ducit.* Newton distinguished the inscrutable cause of the physical attractions by the name 'force of attraction;' he observed its effects, arranged them, and detected the laws of motion, and thus established a useful doctrine, honorable to human genius. In this way we ought to proceed in the study of the nervous system; the cause latent in the nervous pulp, which produces certain effects, and which hitherto has not been determined, we shall call *vis nervosa;* its observed effects, which are the functions of the nervous system, we shall arrange, and expose their laws."[1] Prochaska would use this term in a broader sense than Haller, who confined it to the power with which a nerve caused a muscle to contract. His first law is that the "vis nervosa requires for its action a stimulus, as a blow is necessary to elicit sparks from flint." His other laws do not particularly concern us. For example, stimuli which call the vis nervosa into activity may be material or mental. The vis nervosa may be more active *(mobilior)*, or more

[1] Geo. Prochaska. De functionibus systematis nervosi. Fasic. tertius Annotat. Academ. Prag., 1784. (Todd.)

sluggish, requiring stronger stimulus to produce the same effects. It is augmented or diminished by influences which tend to elevate or depress the powers of life. Prochaska's leaning toward an electrical explanation of nervous phenomena appears early in his career, before the discoveries of Galvani were made known. For example, he recognizes the influence of nerves upon the blood supply to a region, as in the case of erectile tissue, the reddening of the skin upon irritation, or blushing under emotion, and to account for these facts he advances the notion that augmentation of vis nervosa in any part attracts the fluids of the body thither as "sealing wax when rubbed with cloth becomes electrical and attracts small particles to itself."

One of the most important contributions of Prochaska is the definition of the term "*sensorium commune*," an expression used since Descartes with little significance. It is in connection with this that Prochaska elaborates his ideas of the nature of reflex action. "External impressions," he says, "made on sensitive nerves are propagated with great velocity throughout their entire length to their origin, where, when they have arrived, they are reflected according to a certain law, and pass into certain and corresponding motor nerves, by which again being very quickly propagated to muscles they excite certain and determinate movements. This place, in which, as in a center, nerves of sense and motion meet and communicate, and in which, the impressions of sensitive nerves are reflected into motor nerves is called by a term already received by most physiologists the *sensorium commune*." The law according to which the *sensorium commune* reflects sensory into motor impressions is the preservation of the individual.

To prove that reflex actions may be performed unconsciously, Prochaska instances certain movements of apoplectic patients, the convulsions of epilepsy and movements during profound sleep.

In 1786 came Galvani's brilliant discoveries in electricity and Prochaska, as might be expected, was first to work the new doctrine into an explanation of reflex action. He maintains that any irritating body brought into contact with a

living organism forms a new link in the Galvanic circuit of solid and fluid parts, which constitutes the organism. This causes a quantitative and qualitative change in electric tension which is conducted by the nerves to the brain where it produces sensation. The "changed tension of the brain acts as a reflex of the irritation upon other organs and excites them to peculiar activities adapted to remove the unpleasant irritation and to retain those which are pleasant."[1] Thus reflexes have for their general law the preservation of the organism as before, and are "founded on electrical attraction and repulsion of advantageous or injurious irritations according as the polarities of the organ and the irritation are identical or opposite." So Prochaska went to seed in the idea that "physically considered, vis nervosa is pre-eminently a principle of life which reveals itself to us in electricity.[2] As Eckhard remarks in effect, neither Unzer nor Prochaska had unequivocal experimental grounds of their own, as Whytt had, for believing that reflexes could not take place in peripheral anastomoses.[3]

But the century did not close without witnessing the beginnings of some good experimental work in reflex action. Sir Gilbert Blane (1747—1834), on young kittens, and Legallois (1770—1814) chiefly on rabbits, redemonstrated the experiments of Whytt made on the frog, proving that portions of the cord in these animals, as well, could function as reflex centers for the corresponding parts of the body. But the work of these men marks rather a renewal of interest in this sort of investigation than the contribution of anything really new.

For Legallois, animals are constructed to move and to feel. We might, he says, suppose that the power to do this resides in all parts of the body equally, were it not for the fact that the instant a nerve is cut, all sensation and motion vanishes from the parts below the section. Hence the source of power must be sought in the source of the nerves, i. e., in the brain and spinal cord. Destroy these, and all power of motion or

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[1] Prochaska. Physiologie. Vienna, 1820, p. 85. seq.
[2] Prochaska. Vorrede, pp. 9 and 10.
[3] Eckhard, op. cit. p. 50.

sensation is irrevocably lost. But, "if instead of destroying the cord, transverse sections are made, each part of the body corresponding to each section retains its own sensation and voluntary motion; but the sections act without harmony and as though independent of each other, as if, in fact, the sections had been carried through the entire body of the animal. In a word there are as many distinct sensory centers as there are segments of the cord."[1]

The committee appointed to report on Legallois' memoir explained that he believed that the cord acted not merely as a medium of communication between different parts of the body, but that the principle of life and the power which animates the whole body proceeded from it.[2] To prove this, it was admitted, Legallois brought forward abundant and conclusive experiments. Another important point brought into prominence by the use of warm blooded animals is the direct and immediate dependence of life in the cord upon the free circulation of blood through it. Thus while Legallois contributed little that is entirely new, he certainly emphasized and enlarged that which is of most value in the work of his predecessors, and gave to investigation of nerve action a new impetus and direction.

The truth itself could hardly have awakened more profound and universal interest than the error of Galvani, already described in the introductory chapter. But with this excitement naturally enough arose a cloud of speculations which again involved the subject of nerve action in lawless confusion. Even Alexander von Humboldt, as late as 1797, was led, in spite of the good experimental evidence of Whytt, into the most laborious attempts to explain sympathy between different nerves by "conduction" and anastomoses, and proximity of origin of nerves, and by the fact that one nerve lies in the "sensible atmosphere" of another.

How this confusion is cleared up by the timely discovery of a law as important to nervous action as that of circulation to the physiology of the blood must be reserved for a subsequent chapter.

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[1] Œuvres de Legallois, Paris, 1830, Vol. I, p. 135–6.
[2] Legallois. op. cit., Vol. I, p. 265.